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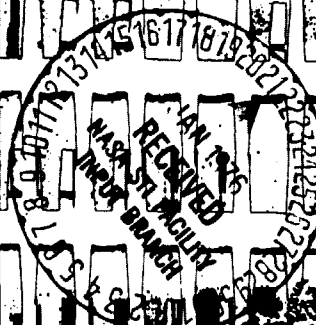
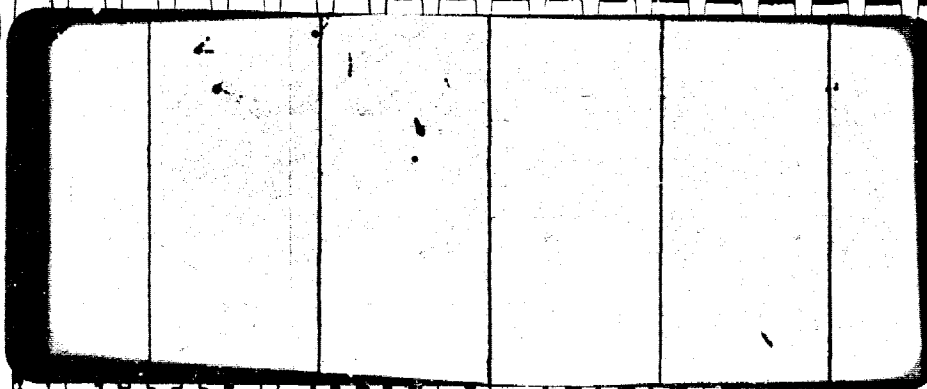
TRW

(NASA-CR-146062) STUDY OF SAFETY
IMPLICATIONS FOR SHUTTLE LAUNCHED SPACECRAFT
USING FLUORINATED OXIDIZERS. VOLUME 2:
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SYSTEMS GROUP

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**STUDY OF SAFETY IMPLICATIONS
FOR SHUTTLE LAUNCHED SPACECRAFT
USING FLUORINATED OXIDIZERS**

**FINAL REPORT
November 1975**

**VOLUME II
EXECUTIVE SUMMARY**

**Prepared For
CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY**

**Under Contract No. 954034
A subcontract under NASA Contract NAS7-100
(Task Order No. RD-156)**

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by TRW SYSTEMS GROUP under JPL subcontract.
Its content is not necessarily endorsed by
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ABSTRACT

This study was a pre-phase A study initiated under NASA contract by JPL to investigate the safety implications of Space Shuttle launched spacecraft that use liquid fluorine as the oxidizer for spacecraft propulsion.

The reference spacecraft, for study purposes, was similar to a MJS 77* Mariner in configuration.

Fluorine based retropropulsion will be needed in the future to effectively conduct a number of planetary orbiter missions particularly those to outer planets. Technically, the concern for Space Shuttle launched spacecraft consists of safely loading, transporting and carrying into space a tank containing typically 1000 pounds of liquid fluorine which is a cryogenic, toxic, and potentially corrosive fluid.

Feasibility of safe operation was investigated and the equipment and procedures necessary to maximize the chance of success determined. Hazards to the Shuttle were found to be similar in kind if not degree to those encountered in use of nitrogen tetroxide (also a toxic oxidizer). It was concluded that residual risks from spacecraft using fluorine and nitrogen tetroxide oxidizers during ground and flight handling may be reduced by isolation of the oxidizer to only its tank. Operation of planetary spacecraft propulsion in the vicinity of the Shuttle in earth orbit is not required. Proper recognition of the characteristics of both of these oxidizers must be given in spacecraft design and in ground and flight operations. Safety precautions appropriate to payloads carried in manned vehicles were developed in the study.

The primary hazard to personnel was identified as propellant loading operations which are very similar in nature to routine transfers from the truck trailers used during delivery of fluorine to industrial users. These operations should be accomplished in an area reasonably remote from personnel and facilities concentrations.

Transportation and installation of the loaded propulsion system involve hazards second only to loading propellant where great care must be exercised. Clearing the pad during spacecraft mating with the Shuttle Orbiter is recommended.

*Mariner Jupiter Saturn designated for launch in 1977

The considerations relating to transport of the spacecraft bipropellant propulsion systems considered here have much in common with carrying of other propulsive payloads such as monopropellant hydrazine systems, and the OMS kits which utilize N_2O_4/MMH . The selection of solid propellant for the IUS would appear to eliminate the hazard of propellant leakage from the IUS.

Residual hazards during flight in the Shuttle cargo bay from a propulsion system which has been subjected to propellant loading, storage, transportation and installation in the Orbiter appear low. It is important, however, that hazards to the propulsion system from the failure of other systems also in the cargo bay are minimized.

To maximize the probability of success, basic work should be continued and expanded with goals delineated to be matched against specific criteria.

FOREWORD

The principal purpose of this study was to ascertain the more important effects on the Space Transportation System (STS) when liquid fluorine (LF_2) is transported on the STS as part of a Shuttle-launched spacecraft. The study might best be categorized as a pre-Phase A study. Planetary orbiters will probably require bipropellant systems, so it was clearly desirable to study the effects attendant with a space-storable propellant such as LF_2 as compared to an earth-storable propellant. The oxidizer selected for comparison with fluorine was nitrogen tetroxide (N_2O_4), because it is an acceptable oxidizer for transport on the Shuttle.

The second purpose was to evaluate, on the basis of these effects, the feasibility of carrying fluorine as part of a Shuttle payload. There is always a risk to Shuttle from carrying any oxidizer or high pressure gas. The basis for judgment was whether or not the risks associated with a propulsion system containing fluorine could be reduced to the level of one containing N_2O_4 . The comparison method (LF_2 versus N_2O_4) was used throughout the study to give it the proper perspective since some type of oxidizer is normally required for the propulsion system of a planetary orbiter spacecraft.

The study begins with the loading of the spacecraft propulsion system at ETR and concludes with deployment of the IUS/Tug, and it also considers Shuttle abort modes.

The scope of the present study tended to broaden as it progressed, and the initially budgeted effort was not large enough to examine a number of interesting areas. The question of whether or not to dump propellant in case of abort, for example, could not be resolved within the resources available, so an arbitrary choice to assume dump would be required was made for purposes of conservatism in continuing the study.

The uncertainty surrounding the selection of the Interim Upper Stage until just before the study ended precluded an evaluation of some of the effects on that vehicle. Thus, the emphasis is on interfaces between the Shuttle Orbiter and the spacecraft propulsion system, with a dump provision conservatively assumed.

To answer the question, "What is required to prove that fluorine can safely be used as an oxidizer in Shuttle-launched spacecraft?" requires that specific and detailed configuration of spacecraft, IUS/ Tug and Orbiter be known. The present study necessarily addresses this question from a more general point of view. No unique technical problems were found that could not be resolved.

In view of this result, it is concluded that with proper design of flight and ground support hardware, adequate test and operations procedures, and thorough training of personnel, the hazards associated with fluorine can be reduced to a level equivalent to that of nitrogen tetroxide.

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1. INTRODUCTION

1.1 INTRODUCTION

The Space Shuttle or Space Transportation System (STS) will introduce a new era in transportation, the era of routine flights and operations on orbit. Now that the capabilities of the STS are known, potential users such as the spacecraft community are investigating how best to utilize these capabilities.

Space exploration missions which involve orbiting of Mariner class spacecraft around the outer planets are of great interest. Representative spacecraft for these missions are shown in Figures 1-1 through 1-3. Figure 1-2 illustrates the flight configuration spacecraft as it is conceived with earth storable propellants and in the deployed configuration.

In order to accomplish several of these missions using the Shuttle Upper Stage, (SUS) and with reasonable flight times, it has been found most effective to utilize the high level of planetary retro-propulsion performance that can only be obtained with fluorine or fluorine containing oxidizers.

With space storable propellants (liquid fluorine and hydrazine) a configuration similar to that above is anticipated, however space storage of the fluorine will require an adequate "view" from the fluorine tank to space which may require some outward repositioning of the fluorine tank. Figure 1-3 illustrates the same spacecraft in the undeployed configuration with a disposable outer shroud or fairing. During transport, the fluorine is kept cool by liquid nitrogen from a dewar or, for limited periods, its own thermal inertia. The reference spacecraft is similar to that anticipated for a MJS 77* Mariner in configuration.

*Mariner-Jupiter designated for launch in 1977.



REPRESENTATIVE MJO SPACECRAFT ISOMETRIC

Flight Configuration
Earth Storable Propellants

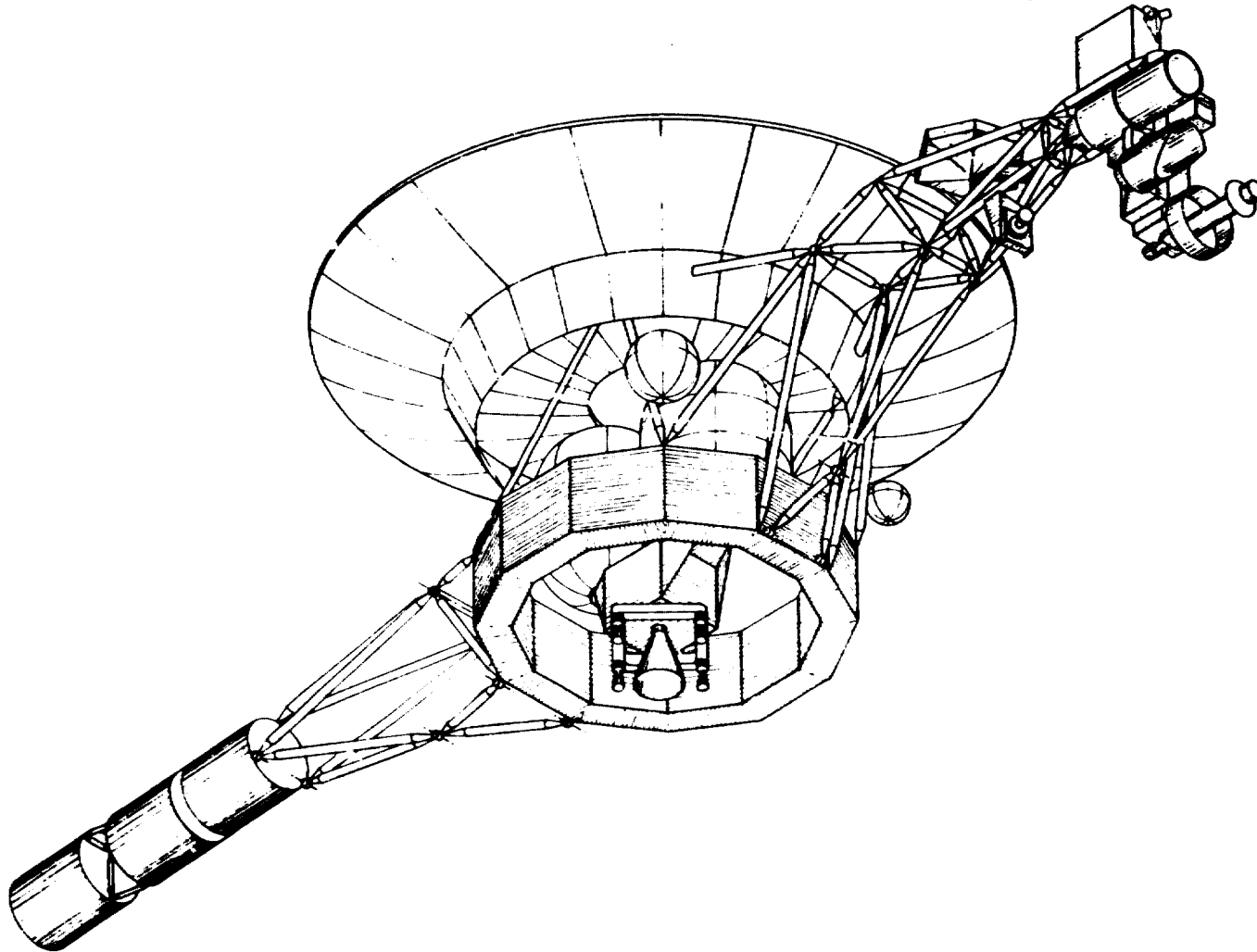


Figure 1-1



REPRESENTATIVE MJO SPACECRAFT

Flight Configuration
Earth Storable Propellants

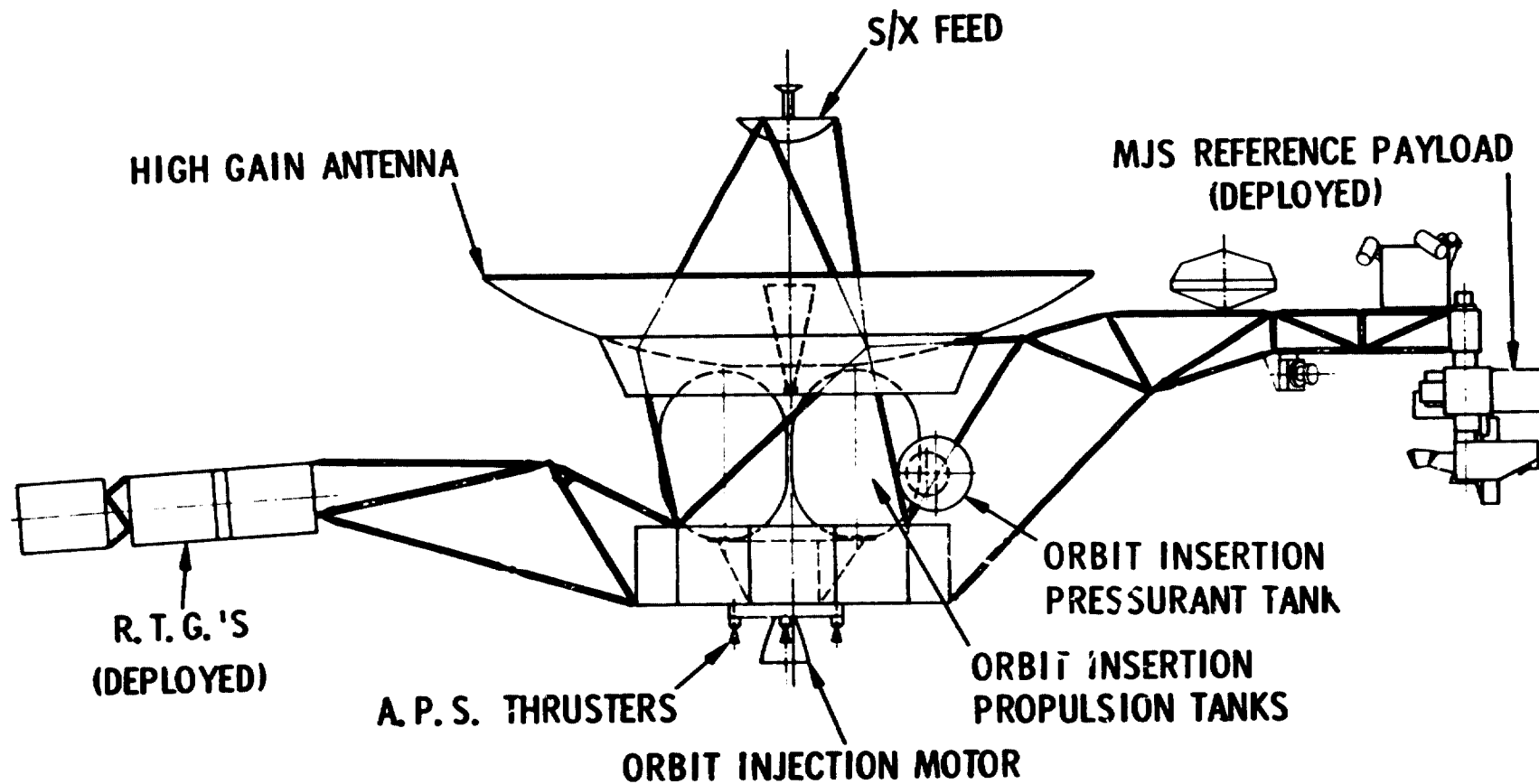


Figure 1-2

REPRESENTATIVE MJO SHUTTLE LAUNCH S/C CONFIGURATION

Disposable Shroud Option
Earth Storable Propellants

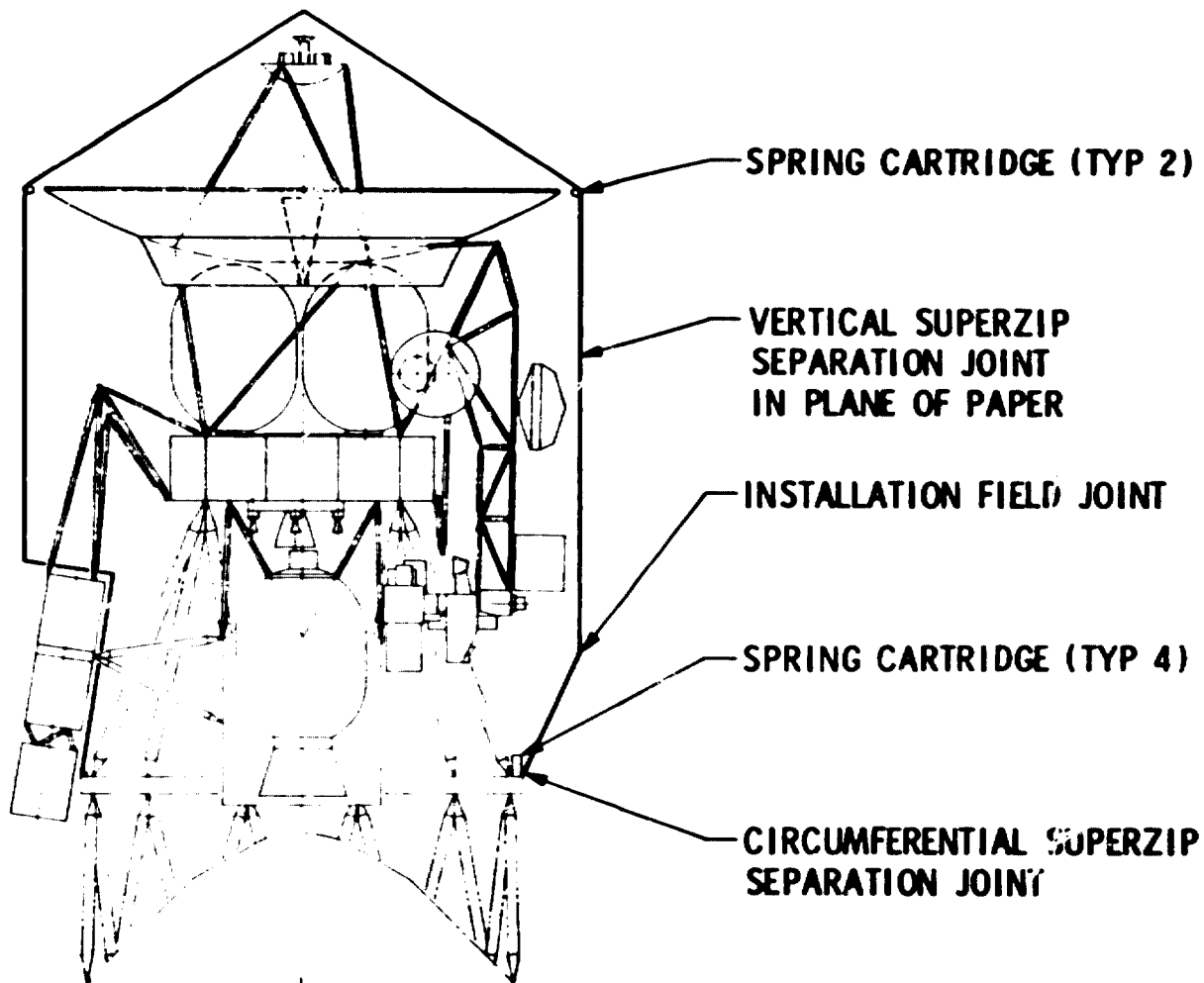


Figure 1-3

The technical concerns which led to this study were the safety questions associated with a Space Shuttle launched spacecraft involving propellant loading, transporting and carrying into space in a manned vehicle a tank containing typically 1000 pounds of liquid fluorine which is a cryogenic, toxic, and potentially corrosive fluid. Schematic diagrams of a current nitrogen tetroxide/monomethyl hydrazine (N_2O_4/MMH) propulsion system and a conceptual fluorine/hydrazine (F_2/N_2H_4) propulsion system are shown in Figures 1-4 and 1-5.

This pre-phase A study was needed since the tractability (suitability and acceptability) of fluorine as a cargo in the Space Shuttle was not known. Of prime interest in the study were safety aspects, as they constrain spacecraft design, and might affect the design of interfacing systems including shroud, tug and orbiter. Processing sequence and storage in the Shuttle of liquid fluorine, as compared to nitrogen tetroxide, also required clarification.

The basic objectives of this investigation, therefore, were to highlight safety implications resulting from a study of ground and flight operations; that is, to assess the unique crew and Shuttle hardware safety implications which would result from fluorine/hydrazine, LF_2/N_2H_4 , propellants as compared to the earth storable combination nitrogen tetroxide*/monomethyl hydrazine, N_2O_4/MMH . These safety implications and the corresponding recommended design requirements include those imposed on the spacecraft, the Space Shuttle, ground support equipment, and during both ground and flight operations.

To accomplish these objectives, it was desirable to assess the relative risks of liquid fluorine, LF_2 , as compared to nitrogen tetroxide for application to planetary spacecraft propulsion launched in the Space Transportation System, and to outline how existing knowledge could be applied to the design of planetary spacecraft propulsion systems to maximize the assurance of safe transportation of fluorine as cargo in the Space Shuttle.

*Also called dinitrogen tetroxide

F₂/N₂H₄ PROPULSION SYSTEM - PRESSURIZED TYPE

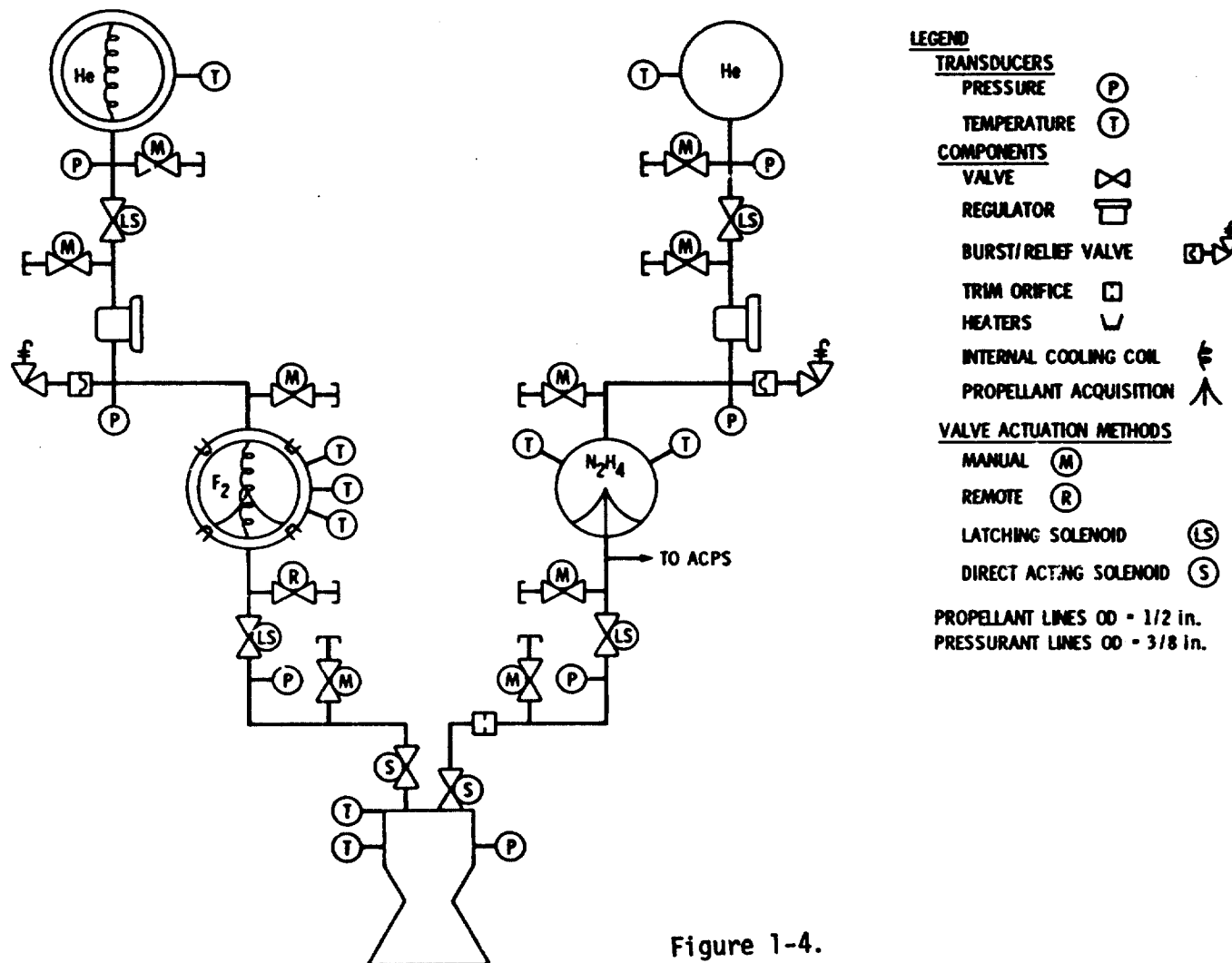
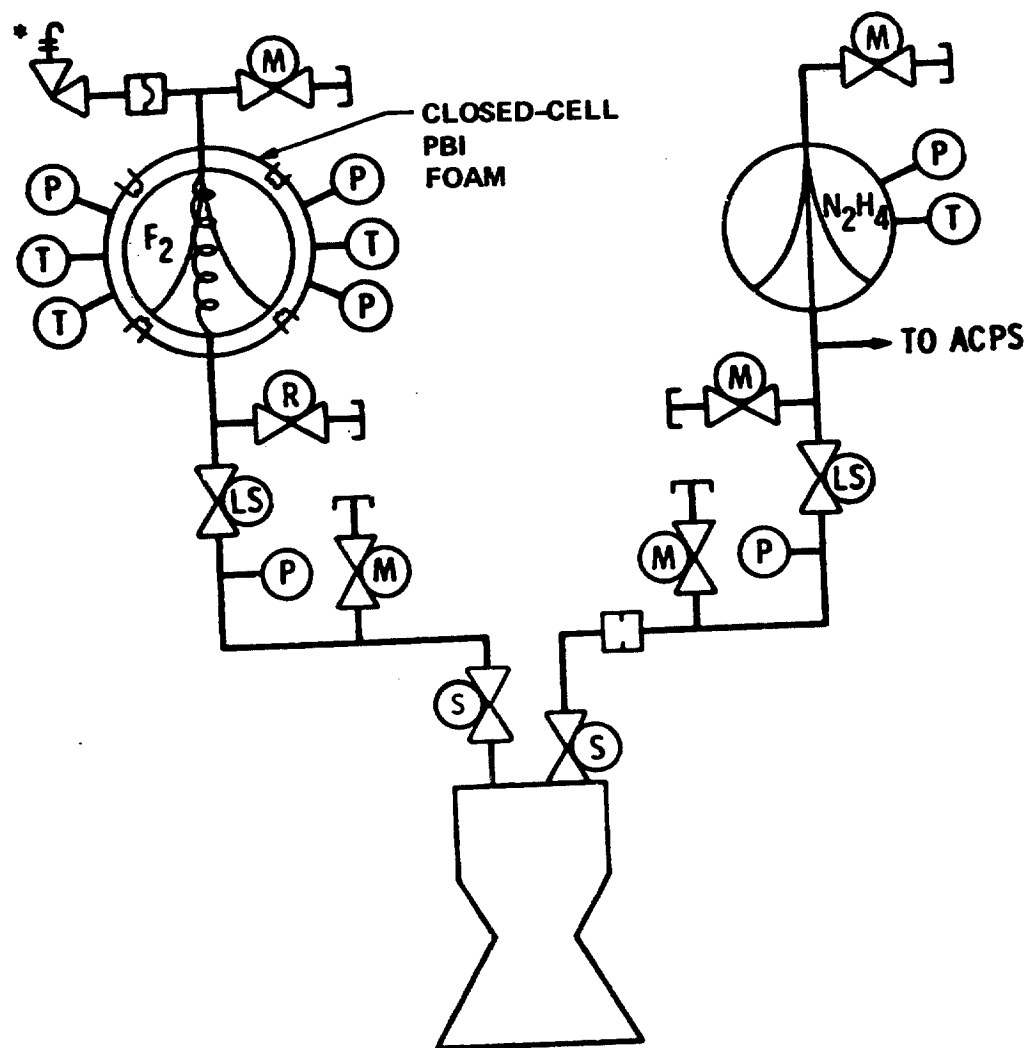


Figure 1-4.

F_2/N_2H_4 PROPULSION SYSTEM - BLOWDOWN TYPE



LEGEND

TRANSDUCERS

PRESSURE (P)

TEMPERATURE (T)

COMPONENTS

VALVE (X)

TRIM ORIFICE (□)

BURST/RELIEF VALVE (B)

INTERNAL COOLING COIL (C)

PROPELLANT ACQUISITION (A)

VALVE ACTUATION METHODS

MANUAL (M)

REMOTE (R)

DIRECT ACTING SOLENOID (S)

LATCHING SOLENOID (LS)

PROPELLANT LINES OD = 1/2 in.

Figure 1-5.

Experience in handling large quantities of fluorine has shown that with suitable design and attention to detail that safe operations can be realized on a day-to-day basis. As an example, liquid fluorine transportation in 5,000 lb. capacity truck trailer-mounted Dewars is carried out routinely with a high level of safety and reliability.

There exists a large technology base with fluorine in the chemical industry and a considerable and growing experience in rocket testing, although no propulsion system using fluorine has yet flown (although a small container of fluorine was launched from Wallops Island). Numerous programs have been sponsored by NASA involving many aspects of fluorine rocketry. The Department of Defense has also sponsored extensive work in fluorine rocketry. Although some incidents have occurred on some of these programs, techniques have been developed to overcome the difficulties. At TRW alone, over 2000 tests of fluorine combustion devices have been conducted over the last eight years.

2. SCOPE AND CONCLUSIONS

2.1 Scope

In this summary, only the most pertinent findings of the study will be discussed. Much more detail, of course, is contained in the main text in Volume I.

The scope of this pre-phase A study was intended to be an overview aimed at identifying the major considerations. The study, was limited by funding and by the preliminary nature of the Space Shuttle and Tug design, payload processing options, and plans for launch complex facilities. Definition in some of these areas, however, evolved significantly during the course of the study.

It was the purpose of this study to compare crew and Shuttle hardware safety interfaces which would result from the use of candidate earth storable and space storable (such as F_2/N_2H_4) propulsion systems including those of the spacecraft, launch vehicle, ground support and on-ground and flight operations.

From a technical standpoint two propellant systems were compared. One is the fluorine/hydrazine combination. The other is the well known nitrogen tetroxide/monomethyl-hydrazine combination used on the Shuttle Orbit maneuvering system. In either case the oxidizer weight did not exceed 3000 pounds.* Both blowdown and externally regulated pressurization systems were considered.

It was assumed that launches will be from KSC using the Space Shuttle (STS) as the carrier with its payload a Mariner spacecraft and SUS. The NASA designated SUS (also called IUS/TUG in this report) is assumed to be used to accelerate the Mariner spacecraft towards the vicinity of the target planet.

*This corresponds to 5000 lbs of total propellant weight which is as much as is ever required by a Shuttle launched planetary orbiter.

Emphasis was placed on both hazard identification and design solutions to minimize or eliminate credible hazards.*

In performing this study, TRW drew on the results of a number of previous and concurrent studies that involve the use of F_2/N_2H_4 in advanced space propulsion systems and other experience in the use of F_2 as oxidizer at TRW's test facility. Safety aspects of handling liquid fluorine in preflight and flight operations or in a ground-based test facility are closely related. Since there is not as yet any experience with Space Shuttle launched spacecraft propulsion, it was necessary first to identify procedures for earth storable N_2O_4/MMH propellants.

After completion of each of the study tasks considering earth storable propellants, the study program tasks were completed for space storable propellant to clearly specify how and why the use of the space storable propellants might change the safety study results.

The study utilized system safety engineering methodology to investigate potential hazards and system design engineering to define how existing technology could be used to provide safe operations.

Due to the value of the Shuttle and its facilities and the manned aspects of Shuttle Orbiter operations, which may have their only precedent in the Apollo program, significant safety precautions are required. In response to this need, compromises of the spacecraft propulsion to achieve increased safety have been considered which appear to be acceptable in terms of performance and cost.

*i.e., one which might reasonably exist or occur.

This study was accomplished in two phases. During the first phase the twelve tasks of the work statement were addressed. Participation and review of this study by NASA Headquarters, JSC, MSFC, KSC and LRC was accomplished by several trips and numerous telephone calls and by mail communications. As the program progressed in the second phase the alternative design concepts and trade-offs involved in safe transport of a loaded spacecraft in the Space Shuttle emerged.

Concepts for transport of earth storable N_2O_4/MMH tended to follow the approaches being evolved for 1) use of earth storable (Transtage or Agena derivative) IUS concepts, 2) the OMS kits and 3) hydrazine RCS systems on proposed earth orbital spacecraft. Concepts for transport of the space storable (cryogenic) LF_2/N_2H_4 system evolved from 1) the earth storable concepts, 2) previous studies for expendable booster launched, LF_2 based, upper stage propulsion and 3) concepts for cryogenic LO_2/LF_2 IUS or Tug designs.* As the study progressed there was an on-going evolution of the Shuttle payload accommodations, requirements and criteria. The IUS and Tug concepts also continued to evolve. The structure of the study as it was accomplished can be summarized by nine elements:

1. Accumulated design concepts, requirements and criteria.
2. Established study format based on system safety engineering techniques.
3. Compared safety parameters
4. Conducted hazard analysis
5. Proposed design concepts, processing sequences and procedures to eliminate or mitigate hazards
6. Evaluated alternate concepts and selected those most promising
7. Documented results
8. Reviewed with sponsoring agency
9. Refined the results and determined recommended follow-on work

*The decision to use solid propellant for the IUS came at the end of the study.

2.2 Conclusions

In the rest of this volume, the overall results of this study are summarized by main topics of interest including:

- Effect of fluorine as compared to N_2O_4 on KSC operations
- Effect of fluorine as compared to N_2O_4 on ETR operations
- Effect of fluorine as compared to N_2O_4 on Shuttle Post Launch operations
- Effect of fluorine as compared to N_2O_4 on the Shuttle Orbiter and the Shuttle Upper Stage
- Effect of fluorine as compared to N_2O_4 on Spacecraft Propulsion System design
- Safety conditions for LF_2 as compared to N_2O_4
- Conclusions and recommendations

In Sections 3 and 4 of Volume I, the technical background for the use of fluorine and the detailed exposition of the original twelve tasks of the study are described. The appendices of Volume I include important data as to the JPL design concept, glossary of terms and launch site and flight hazard analyses.

This study was limited to some degree by the unavailability of detailed information about the Shuttle Orbiter as no description of propellant dump accommodations or their design criteria for the Orbiter was available. Also, only limited data on the Payload Changeout Facility was available. Some data became available too late for inclusion in this report.

3. SAFETY PARAMETER COMPARISON OF LF_2 VS N_2O_4

Comparison of safety aspects between propellants involves a number of considerations related to physical and chemical properties of the propellants and physiological effects on humans. Some of these aspects are compared in Table 3-1.

Table 3-1.

COMPARISON OF SAFETY ASPECTS

ASPECT	N_2O_4	LF_2
1. STATE OF LIQUID AT USE	~ 50 PSIG EARTH STORABLE	0 PSIG GRYOGENIC
2. EMERGENCY EXPOSURE LIMIT, PPM	30 (10 MIN. NO_2)	15 (10 MIN.)
3. OSHA LIMIT, PPM**	(5.0 NO_2)*	0.1 (QUESTIONABLE)
4. THRESHOLD LIMIT VALUE***	(5.0 NO_2)*	1.0 (REVISED FROM 0.1)
5. BREATHING	INDIVIDUAL WILL DAMAGE HIMSELF UNKNOWINGLY	WILL NOT BREATHE OVER 25 PPM (5 MIN. EEL)
6. OLFATORY DETECTION	NOT UNTIL EEL	IMMEDIATE AT TLV
7. PHYSIOLOGICAL EFFECTS AT SELF-DETECTION	DELAYED PULMONARY EDEMA	MINOR OR NONE
8. TOXICITY OF REACTION PRODUCTS	BETTER: NO_2 , NO , N_2 , H_2O	WORSE THAN FOR N_2O_4 ; HF
9. VULNERABILITY IN USE	UNINSULATED	INSULATED
10. FIRE CONTROL	DIFFICULT	DIFFICULT
11. EXPLOSION	0.05 TNT/LB	~ 0.02 TNT/LB ROM
12. SPILL DISPERSAL	WORSE	BETTER

* N_2O_4 DISSOCIATES TO NO_2 IN THE ATMOSPHERE

** 8 HOUR WORK DAY

*** REFERENCE 1 - THRESHOLD LIMIT VALUE FOR REPEATED 8 HOUR WORK DAY

A major difference in the two oxidizers is that fluorine is only liquid at cryogenic temperatures. This requires that cooling must be supplied, such as by liquid nitrogen, except for relatively brief periods determined by the thickness and efficiency of the tank insulation.

Both propellants are toxic, but can be detected by smell. Detection of N_2O_4 occurs only at a much higher concentration, however, and a person can fail to detect harmful concentrations. Work area concentrations allowed by law under the Occupational Safety and Health Act* are much lower for fluorine than for N_2O_4 .

Toxicity of fluorine on the applicable basis of ten minute Emergency Exposure Limits, EEL, is 15 ppm versus 30** for N_2O_4 a ratio of 2:1. Inhalation by personnel of a much higher concentration of fluorine than the EEL is considered impossible because its stifling effect is so severe that choking and asphyxia would result if relief or escape were delayed. At comparably toxic levels with N_2O_4 a person is less aware of the danger and may collapse the next day from a delayed pulmonary edema.

Under conditions of reaction of the oxidizers with other materials, such as fuels or water, N_2O_4 decomposes to form the less toxic substances NO_2 and NO . It reacts with water to form nitric acid and with carbon to form carbon dioxide or carbon monoxide. Fluorine reacts with water to form the somewhat less toxic HF and with carbon to form inert CF_4 . Reaction with carbon (charcoal) can be used to dispose of LF_2 .

In case of a fluorine spill, ambient heat can turn the liquid to vapor in a matter of one to ten minutes. For a spill of N_2O_4 a somewhat longer release time would be involved although N_2O_4 boils at a relatively low $21^{\circ}C$ ($70^{\circ}F$). The dispersal of spilled LF_2 is considered to be somewhat better because of the lower molecular weight of fluorine as compared to N_2O_4 , NO_2 and HNO_3 and because reaction with atmospheric moisture

*Safety and Health Standards Section 1900-1000 Subpart Z, Table 2-1 as of May 1975. Occupational Safety and Health Administration.

**Parts per million

tends to produce heat in the cloud which encourages vertical dispersion. Spill tests with LF_2 were conducted at AFRPL in quantities of approximately 1000 lbs. Data from these tests can be used as a rough guide in formulating distances for personnel concentrations during propellant flowing and handling in this application.

Both propellants are hypergolic with amine (hydrazine based) fuels. Fluorine, however, is also hypergolic with many other fuels, and even reacts vigorously with water producing hydrofluoric acid, oxygen, and steam. Fire control is thus difficult, as it is with other strong oxidizers.

Explosive hazard estimation involves certain assumptions and depends on the fuel available, but because of the somewhat greater reactivity of fluorine, its explosive potential is considered less than N_2O_4 because it is more difficult to achieve a concentrated mixture of reactants.

4. EFFECT OF FLUORINE AS COMPARED TO N_2O_4 ON KSC OPERATIONS

4.1 Spacecraft Processing Options

Many processing options were considered to determine how the empty spacecraft propulsion system should be loaded with oxidizer and how the installation into the Space Shuttle should be accomplished.

The two loading alternatives considered were:

1. Loading of the spacecraft tanks remotely from the pad.
2. Loading of the spacecraft tanks at the pad.

Remote loading was clearly indicated.

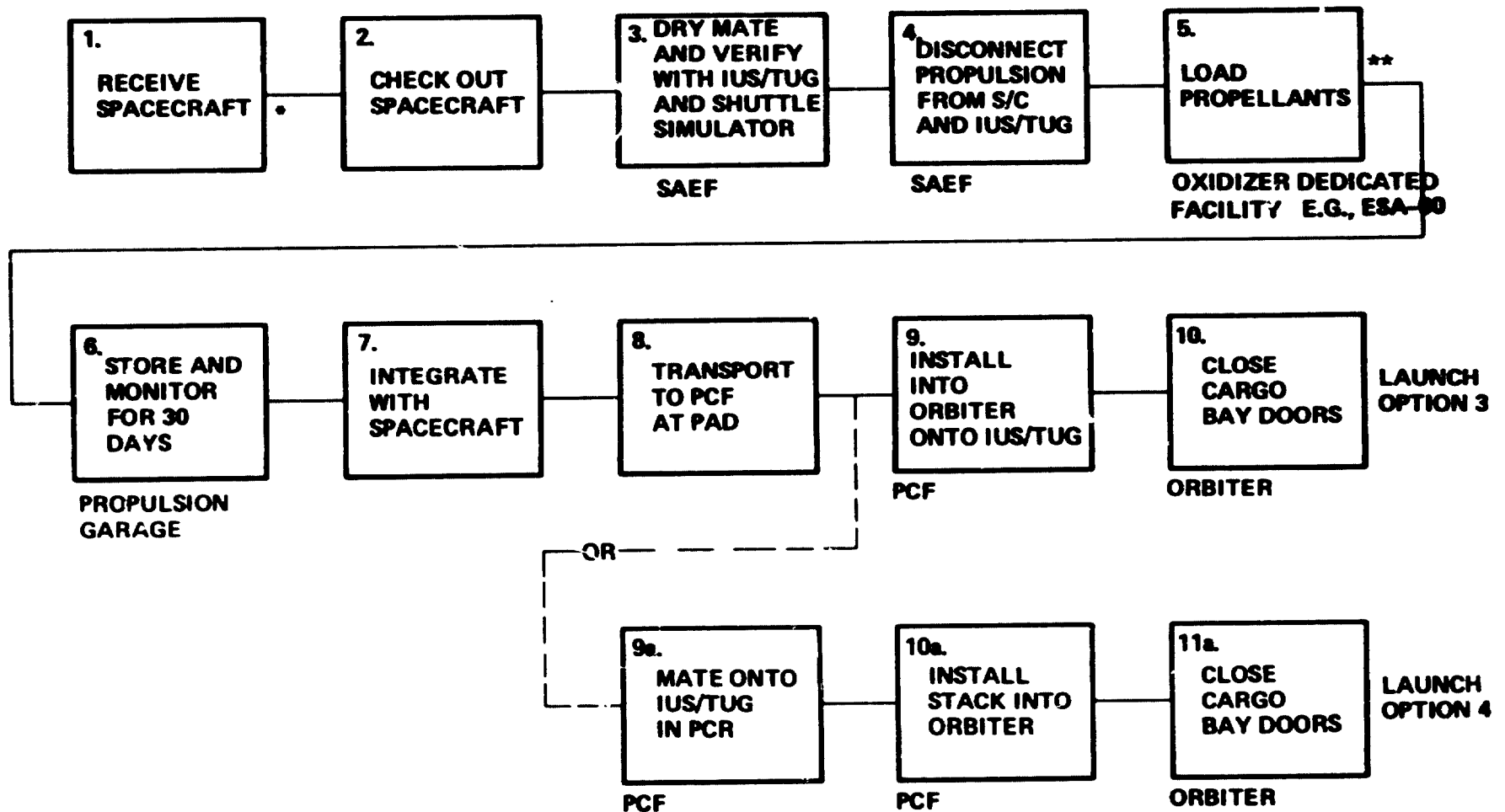
The other main consideration was whether the spacecraft should be installed into the Shuttle Orbiter in the normal payload processing location at the Orbiter Processing Facility, or via the Payload Changeout Room at the pad.

Other variations of integration sequence with the IUS or Space Tug were also considered. As for comparisons between the two oxidizers, there is no basic difference in the recommended processing sequences for LF_2 and N_2O_4 except as noted later.

The recommended sequence was based on the following criteria:

1. For safety of KSC personnel and the Shuttle, spacecraft propellant should be loaded remotely from the pad.
2. Mating of the spacecraft with the IUS/Tug should be done either in the Shuttle Orbiter Bay or in the Payload Changeout Room to avoid transporting spacecraft propellant through the OPF and VAB.
3. In order to verify form, fit, and function of the interfaces between the Spacecraft and the IUS/Tug and the Spacecraft and the Orbiter, a preliminary "dry" mating may be required with the IUS/Tug and Shuttle or Shuttle simulators. This would be done early in the schedule of prelaunch operations.
4. The resulting steps are shown in Figure 4-1.

SELECTED PROCESSING SEQUENCES



• A SPARE PROPULSION SYSTEM MAY BE INCLUDED

** LF_2 REQUIRES LN_2 COOLING IN ALL SUBSEQUENT STEPS UP TO LAUNCH

Figure 4-1.

The only difference between sequences recommended for LF_2 and that for N_2O_4 is that liquid fluorine requires cooling from the time of propellant loading until launch.

In this sequence, the spacecraft is received at the launch site and checked out to verify that no damage occurred in transportation. Next it is dry* mated with the IUS or Tug in a location such as the Spacecraft Assembly and Encapsulation Facility to verify compatibility of form, fit and function of the mechanical and electrical interfaces. Verification of compatibility with the Shuttle by means of a Shuttle Simulator is also anticipated. These checks would minimize the chance of a loaded spacecraft meeting the IUS/Tug or Shuttle for the first time at the pad in an incompatible condition which could impact the prelaunch schedule and hence threaten a slip in the launch-readiness date.

Next the spacecraft propulsion is isolated and taken to a remotely located Oxidizer Dedicated Facility, for example ESA-60 suitably modified. Propellant loading always, of course, takes place with minimum personnel exposure.

After an appropriate stabilization period it is recommended that the loaded propulsion be taken to a "propulsion garage." The propulsion garage is a remotely located building of simple construction which is suitable for storage of the propulsion system. The propulsion system is monitored for leakage or other changes of status.

As the launch readiness date approaches, the loaded propulsion system and spacecraft are integrated and transported to the Payload Changeout Facility. Depending on the design of the spacecraft and IUS/Tug, integration of the spacecraft and IUS or Tug occurs either inside the Shuttle Cargo Bay or in the Payload Changeout Room, (option 3 or option 4).

*i.e. empty of propellants

4.2 Spacecraft Timeline for Pre-launch Operations

Spacecraft timelines for LF_2 and N_2O_4 are virtually identical except for a few hours required to disconnect and reconnect N_2 cooling lines when the propulsion system is moved after loading. A period of thirty days in the loaded condition is considered appropriate to gain assurance that the tank is sound.

4.3 Shuttle Timeline for Pre-launch Operations

Shuttle timelines for LF_2 and N_2O_4 are expected to be the same except for an additional period for LF_2 spacecraft not exceeding three hours. This time period is considered necessary to 1) clear the pad for arrival of the loaded spacecraft (one hour), 2) clear the pad for reconnection of LN_2 coolant at the Payload Changeout Room (one hour), and 3) clear the pad for reconnection of the LN_2 coolant after installation in the Orbiter (one hour). All of the effects of propellant safety considerations including pad clearance times total a maximum of six hours for N_2O_4 and nine hours for LF_2 as shown in Figure 4-2.

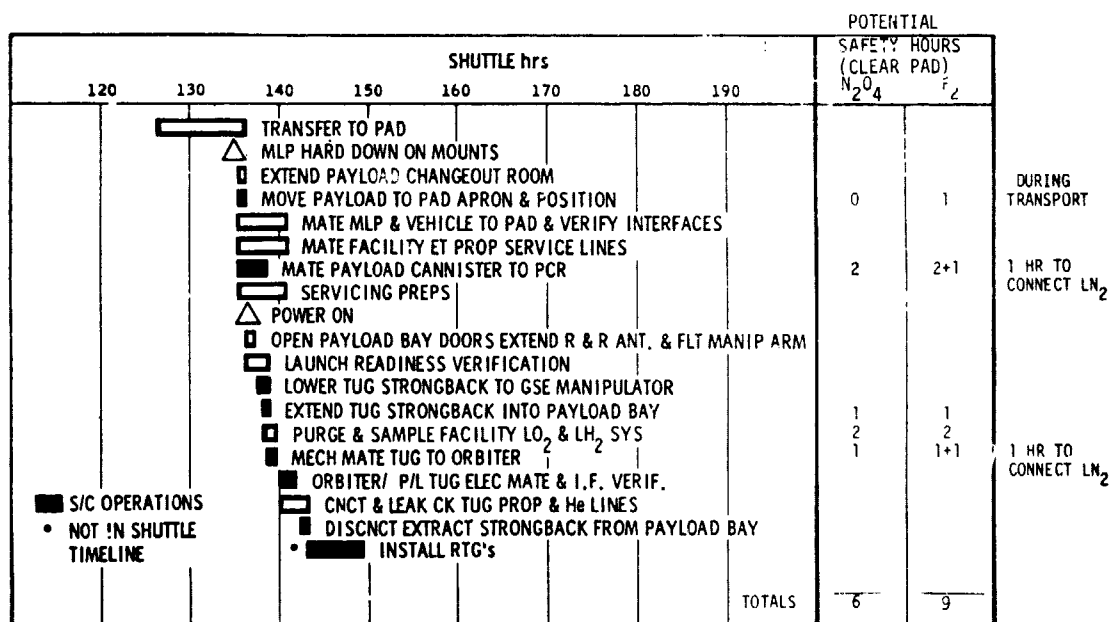


Figure 4-2. Launch Pad Operations

5. EFFECTS OF FLUORINE AS COMPARED TO N_2O_4 ON KSC FACILITIES - PAYLOAD CHANGEOUT FACILITY

Effects of fluorine as compared to N_2O_4 in the design of and activities in the Payload Changeout Facility are similar to those at the spacecraft propellant loading site (ESA). The key items are:

1. Automatic fluorine-specific vapor detection equipment is recommended.
2. Some additional care in evacuating and minimizing personnel during arrival of the fluorine system and its installation into the Payload Changeout Room, (e.g. personnel may be evacuated prior to arrival of the spacecraft). This is due to the somewhat greater toxicity of F_2 .
3. A time allowance for connection of LN_2 cooling to the system after installation in the Payload Changeout Room.
4. Availability of cryogenic LF_2 dewar tank or truck for propellant drain in case of inability to either continue pre-launch operations in accordance with the timeline or "back-out" the propulsion system, whether it is in the PCR or Orbiter Bay.

A leak or spill of fluorine or N_2O_4 at the Payload Changeout Facility would be of much greater consequence than a like incident at the ESA-60 because it would involve more expensive facilities and equipment and could impact the Shuttle timeline. In order to minimize this possibility for either type of oxidizer, the following recommendations are made:

1. Propellant loading to be done remotely.
2. The pad area to be evacuated except for essential personnel during movement of propellant.
3. A continuous monitoring of safety status to be implemented prior to propulsion arrival if not previously instituted. This includes propellant tank temperature, pressure and vapor detection in the PCF.
4. Procedures to be established and practiced to cope with emergencies.
5. Fire control equipment to be available and under control of a well trained person.

6. EFFECT OF FLUORINE AS COMPARED TO N_2O_4 ON ETR FACILITIES

6.1 Spacecraft Explosive Safe Facility

ESA-60 has been successfully used for loading of Mariner spacecraft with N_2O_4/MMH and could presumably be modified to accommodate fluorine. A modified ESA-60 or other oxidizer facility designed to handle fluorine on an intermittent basis will require, as does the N_2O_4 facility, a reactivation prior to and deactivation after each launch. All lines and valves and any tanks should preferably be maintained in a purged, dry and inert condition to prevent possible corrosion by fluorine in combination with moisture.

For use with LF2, the following capabilities would be needed for a modified ESA-60 or other site:

1. Remotely operated fluorine transfer lines for transfer from trailer truck to spacecraft propellant tanks
2. LN_2 cooling equipment and LN_2 dewar
3. Reactors for disposal of fluorine purged from the propellant loading lines
4. A reactor capable of disposal of one full load of propellant in an appropriate time interval
5. Propellant vapor detection equipment for personnel protection
6. Propellant drainage channels in the floor of the building to a treatment sump for fluorine disposal
7. Isolation and compartmentation of the fluorine lines to minimize damage in event of a failure
8. Fire control equipment including tanks for providing water spray or other appropriate fluid
9. Television coverage in color of the loading area with display in the remote control center (color to aid in discernment of the nature of the vapors)

10. A "propulsion garage" remote from other buildings for storage of the propulsion system (to attain personnel safety and protect facilities from corrosion or other damage)
11. Perimeter control of the site during operations to limit access of personnel to the loading site
12. Recognition of meteorological conditions in establishing safe loading periods (which typically occur daily)

7. EFFECT OF FLUORINE AS COMPARED TO N_2O_4 ON SHUTTLE POST LAUNCH OPERATIONS

7.1 Nominal Case

The only effect of fluorine on the Shuttle as compared to N_2O_4 after a normal mission may be the requirement for purging and sealing of fluorine dump lines in the event dumping of spacecraft propellant would be required. It is expected that the requirements for N_2O_4 might be somewhat less stringent.

7.2 Shuttle Abort Cases

After a Shuttle abort, the effects will depend on the type of abort and the condition or state of the spacecraft propellant tank and fluorine dump line (if used). Each abort case is summarized below:

1. Normal complete dump to vacuum (as in abort from orbit) no effects.
2. Dump valve malfunction resulting in a landing while still loaded. This requires connection of a disposal system to the LF_2 and drainage of the propulsion system before further Shuttle processing.
3. RTLS abort in atmosphere with suspected fluorine residue either liquid, solid or gaseous. This requires connection of LN_2 cooling or disposal from the end of the dump line.
4. Return of the Shuttle to an unexpected landing site of opportunity would require some means for cooling the fluorine or disposing of it in a safe manner.

8. EFFECT OF FLUORINE AS COMPARED TO N_2O_4 ON THE SHUTTLE ORBITER AND THE SHUTTLE UPPER STAGE

8.1 Flight Operations and Modes

In normal flight operations, the LF_2/N_2H_4 propulsion system will be disconnected from ground cooling at T-0. It will have on-board cooling for 24-36 hours provided by LN_2 Dewars. The tanks will be unpressurized (1 bar, or 0 psig) from liftoff to deployment of the spacecraft from the Shuttle Orbiter. Prior to use of the spacecraft a back-off maneuver of approximately one mile separation between the Shuttle and spacecraft/SUS will be accomplished. Only after the back-off maneuver will the spacecraft be pressurized. No operation of the spacecraft propulsion will occur until 7-21 days after departure of the spacecraft from earth orbit.

Abort modes considered include:

- o Return to launch site
- o Abort to orbit
- o Abort once around
- o Abort from orbit
- o Landings at landing sites of opportunity

Flight hazards from oxidizers, either N_2O_4 or LF_2 would result from:

- o Tank leakage
- o Tank overpressurization
- o Tank damage
- o Dump system contamination
- o Residual propellants and vapors after flight

In the RTLS, abort hazards could result from either Shuttle caused or payload caused faults. In order to reduce hazards, secondary leakage containment and dump lines were considered. Abort to orbit and abort once around were found to be similar and easier to accommodate as dumping into vacuum could be accomplished and at a more leisurely pace than during RTLS.

AFO could involve a longer time for cryogenic propellant to heat up, however, there is also a longer time to perform propellant dump or payload jettison procedures.

Landings at sites of opportunity could involve additional risks if equipment to handle residual F_2 is not available, however this is a secondary hazard since all oxidizer is assumed normally dumped. There is need for an additional study of this landing mode.

In order to accommodate the spacecraft propulsion, a number of effects on the Shuttle Orbiter will be incurred. Most of these are needed for both N_2O_4 and LF_2 except for the LN_2 coolant supply.

Affected systems in the Shuttle bay are:

1. Common requirements for N_2O_4 and LF_2 :
 - Dump line (LF_2 requires an F_2 passivated line)
 - Spacecraft relief valve effluent line
 - Exclusion of combustibles to the extent possible
2. Specific LF_2 requirement:
 - LN_2 coolant supply

For liquid fluorine a special fluorine dump line may be required, and fluorine oxidizer tank relief lines will be required. A dump line for the fluorine tank will have to be passivated. It is suggested that during flight, helium pressure be maintained in the line to insure its cleanliness.

The effects of possible leakage on the Shuttle Orbiter, if not sufficiently well inhibited by double wall tanks or by vapor tight shroud techniques, would be a need to eliminate all materials from the cargo bay susceptible to ignition by fluorine. This does not appear, however, to be a practical measure. If the fluorine tank is provided with a double wall, the possibility of fluorine vapors in the Shuttle bay may be considered to be reduced to such a low value that vapor containment by the

spacecraft shroud is not necessary. For the N_2O_4 as the oxidizer, a vapor tight shroud should be considered. It was beyond the scope of this study to make final recommendations as to leakage containment techniques. SUS (IUS or Tug) interfaces are probably the same as the Shuttle bay interfaces as these functions will probably be routed through the SUS.

The Shuttle Upper Stage (SUS for this study was designated IUS/Tug) meaning the Interim Upper Stage or Space Tug, and covers both designations as appropriate.

Effects on the SUS or IUS/Tug may include:

1. A dump line and disconnect between the spacecraft and the SUS, and an umbilical fitting at a SUS to Orbiter interface together with an overboard dump line would be necessary if a spacecraft dump requirement is imposed.
2. An oxidizer tank relief line appears to be required. It would be routed from the spacecraft through the SUS and Orbiter interfaces as described in (1) above. Figure 8-1 illustrates this routing.

DUMP LINE CONCEPT

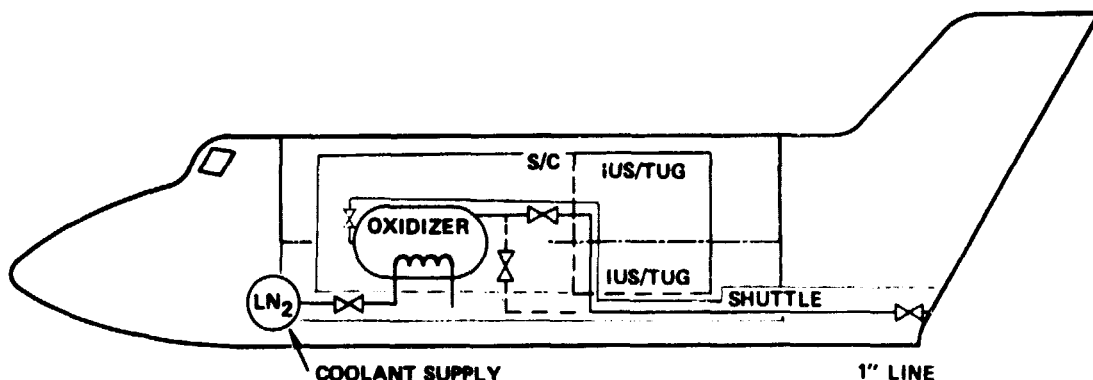


Figure 8-1.

Dumping always occurs at less than 0.1 psi (.007 bar) and can be into the wake of the Orbiter and it is expected that oxidizers will either be quickly diluted by the low pressure atmosphere, or will expand to very low pressures if at orbital altitudes. The Shuttle vents will be closed at this time but are expected to leak. For this reason, some very low vapor pressure of oxidizer could theoretically recirculate into the cargo bay. Although further analysis is suggested it appears highly unlikely that a significant concentration of fluorine could enter the cargo bay via such recirculation.

Cockpit functions will include for either oxidizer tank, status monitors for:

- tank pressure
- tank temperature (for LF_2)
- vapor detection

Modifications needed on the exterior of the Shuttle will include dump ports for the liquids if dump is required and (vapor) relief ports.

9. EFFECTS OF FLUORINE AS COMPARED TO N_2O_4 ON SPACECRAFT PROPULSION SYSTEM DESIGN

9.1 Spacecraft Propulsion Requirements and Technical Base

Substitution of higher energy LF_2/N_2H_4 for the N_2O_4/MMH propellants used in Mariner class spacecraft primarily introduces the considerations related to a cryogenic propellant.

The Shuttle considerations are primarily those of transportation, since the Shuttle is used to transport this propulsion system in an inert state.

The spacecraft propulsion system has;

- No operation in the Shuttle
- No operation near the Shuttle

Only after deployment and after SUS operation does this system perform trajectory corrections and orbit insertions. These events do not begin until 7 to 21 days after departure from earth orbit. Thus, no pressurization of the spacecraft propellant tanks is needed until it is far from the Shuttle.

Parameters of a typical payload propulsion system are as shown in Table 9-1.

Table 9-1.

PAYLOAD PROPULSION SYSTEM CHARACTERISTICS

LF₂/N₂H₄

PROPELLANT WEIGHT, KG/LB

OXIDIZER	454/1000 TYPICAL
FUEL	318/700 TYPICAL

ENGINE THRUST, NEWTONS/LBF **2670/600**

CHAMBER PRESSURE, N/CM²//PSIA **69/100**

TANK PRESSURE, N/CM²//PSIA

OPERATING	241/350
IN SHUTTLE BAY	10/14.7

The system resulting from the study is illustrated schematically in Figure 9-1. It is a four-tank blowdown system featuring propellant isolation. Figure 9-2 illustrates connections.

PROPULSION SYSTEM

4-Tank Blowdown

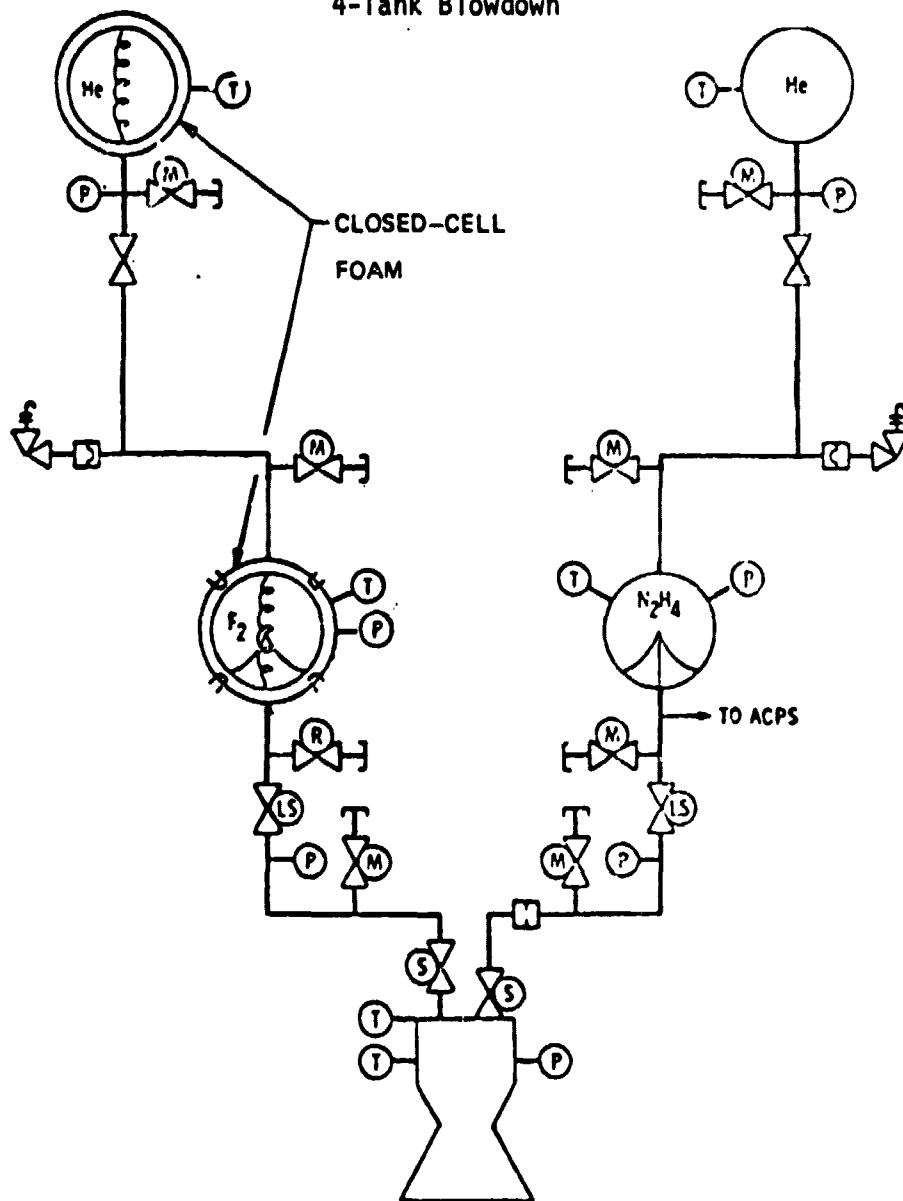


Figure 9-1.

LF₂ PROPELLANT CONTAINMENT ASSEMBLY — PCA AND GSE (OSE) CONNECTIONS

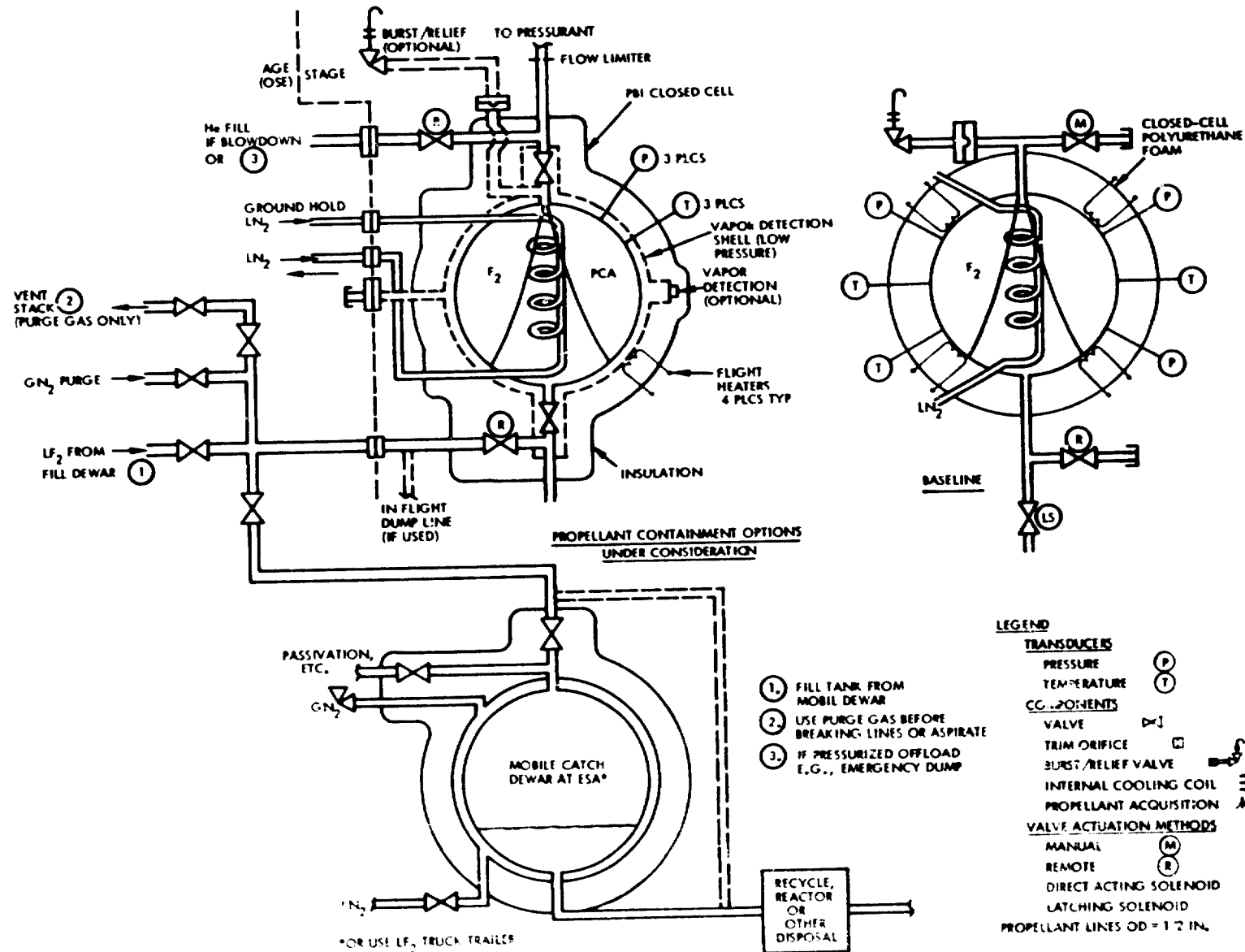


Figure 9-2.

Table 9-2.
 LF_2 Propulsion Hardware Assumptions in the Hazard Analyses

ITEM	STUDY BASELINE SHUTTLE LAUNCH CONFIGURATION		SHUTTLE PREFERRED (MODIFIED) SYSTEM	
	H_2O_4	LF_2	H_2O_4	LF_2
Oxidizer Tank	<ul style="list-style-type: none"> o 6A14V Titanium o 100 psi typical o Can take vacuum o designed for leak before burst 	<ul style="list-style-type: none"> o Can take vacuum o 6AL-4V o Thoroughly cleaned and passivated o Designed for leak before burst 	<ul style="list-style-type: none"> o Same as baseline 	<ul style="list-style-type: none"> o Same o Double wall desirable
Detectors (press, temp, vapor)	<ul style="list-style-type: none"> o Temperature and pressure o Cockpit and ground analog alarm 	<ul style="list-style-type: none"> o Temperature and pressure transducer, alarm and readout o Vapor detector (digital type) o No detectors in cargo bay. o Cockpit and ground, analog and alarm 	<ul style="list-style-type: none"> o Same as baseline o Vapor detector in shroud desirable 	<ul style="list-style-type: none"> o Same as for the baseline design o Also detectors required in the cargo bay. (If ever IVA, e.g., emergency)
Dump/Vent system	<ul style="list-style-type: none"> o Dump capability provided through the IUS/TUG UM81L via kit. Processed through orbiter dump piping 	<ul style="list-style-type: none"> o Same as H_2O_4 (assumed for emphasis) 	<ul style="list-style-type: none"> o Can use other hypergol dump 	<ul style="list-style-type: none"> o Make dump sys compatible with LF_2
Vent or pressure relief system	<ul style="list-style-type: none"> o Gas pressure relief system provided-burst disk and isolation valve in series with burst disk. One for each tank 	<ul style="list-style-type: none"> o No vent system 	<ul style="list-style-type: none"> o Same as baseline 	<ul style="list-style-type: none"> o Specially designed vent system for venting overboard when shuttle bay doors are open only. Contains double redundant burst disk, nozzle, valve piping etc. o Passivation and cleanliness req.
Shroud	<ul style="list-style-type: none"> o Partial shroud (protect electronics) 	<ul style="list-style-type: none"> o Partial shroud (protect electronics) o Not designed to resist F_2 corrosion 	<ul style="list-style-type: none"> o Full leak tight shroud, vented to space 	<ul style="list-style-type: none"> o Full shrouds. The shroud should be designed to be as resistant against LF_2 corrosion as possible and vent F_2 vapor overboard. The shroud shall be designed to prevent leaking of F_2 vapor outside the shroud
Pressure supply (blow-down is pressure regulated)	<ul style="list-style-type: none"> o Separate pressure supply o Regulated system used o Pressurized during launch 	<ul style="list-style-type: none"> o Separate pressure supply o Regulated or equivalent pressure system required o Not pressurized during launch 	<ul style="list-style-type: none"> o Same as baseline 	<ul style="list-style-type: none"> o Regulated or equivalent pressure system provided o Same as baseline
Insulation	<ul style="list-style-type: none"> o Not insulated 	<ul style="list-style-type: none"> o Insulated 	<ul style="list-style-type: none"> o Not insulated 	<ul style="list-style-type: none"> o Insulated, same as for baseline sys
Stresses (vertical horizontal)	<ul style="list-style-type: none"> o Designed for axial and horizontal stresses o Designed for tank to stay in place during crash landing 	<ul style="list-style-type: none"> o Same as for H_2O_4/Shuttle 	<ul style="list-style-type: none"> o Same as baseline 	<ul style="list-style-type: none"> o Same as for H_2O_4/Shuttle baseline except that the liquid in the container should be contained safely in a crash landing
Oxidizer tank shell (contains leaking vapors or liquids)	<ul style="list-style-type: none"> o No shell 	<ul style="list-style-type: none"> o Leak shell provided 	<ul style="list-style-type: none"> o No shell (may use shroud) 	<ul style="list-style-type: none"> o Leak shell provided
Off-load capability	<ul style="list-style-type: none"> o Provided for before launch 	<ul style="list-style-type: none"> o Provided LF_2 compatible dump before launch only 	<ul style="list-style-type: none"> o Hypergolic oxidizer dump system o Emergency deployment 	<ul style="list-style-type: none"> o Off-load capability possible via the vent-sys and the LF_2 compatible dump system
Catch pan system	<ul style="list-style-type: none"> o No catch pan system 	<ul style="list-style-type: none"> o Shell only and no catch pan 	<ul style="list-style-type: none"> o Dike system desirable if not under pressure 	<ul style="list-style-type: none"> o Catch pan and shell

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New propulsion technology available for fluorine propulsion includes compatibility testing, electron beam welding, fracture mechanics techniques, the AFRPL developed bobbin seal, and a better understanding of compatibility and passivation.

Materials selections will be based on experience being acquired at JPL and in the industry on fluorine rocket and corollary high energy combustion devices. JPL has successfully demonstrated a complete self-contained (but not flight weight) F_2/N_2H_4 propulsion system.

9.2 Hazard Analysis

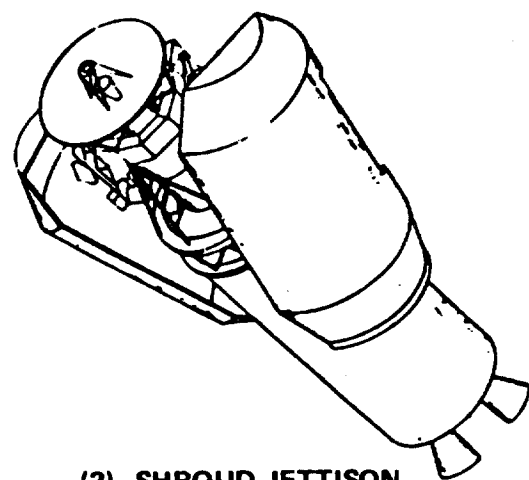
A hazard analysis was conducted, and the results derived from it are largely reflected in the propulsion system design recommendations, discussed later. The details of the hazard analysis are included in the basic document, but the assumptions upon which the analysis was based is presented in Table 2-3 on the last half of the page. The changes in these assumptions, as a result of the hazard analysis, are shown on the right half of the Table.

9.3 Spacecraft Propulsion System Design Recommendations

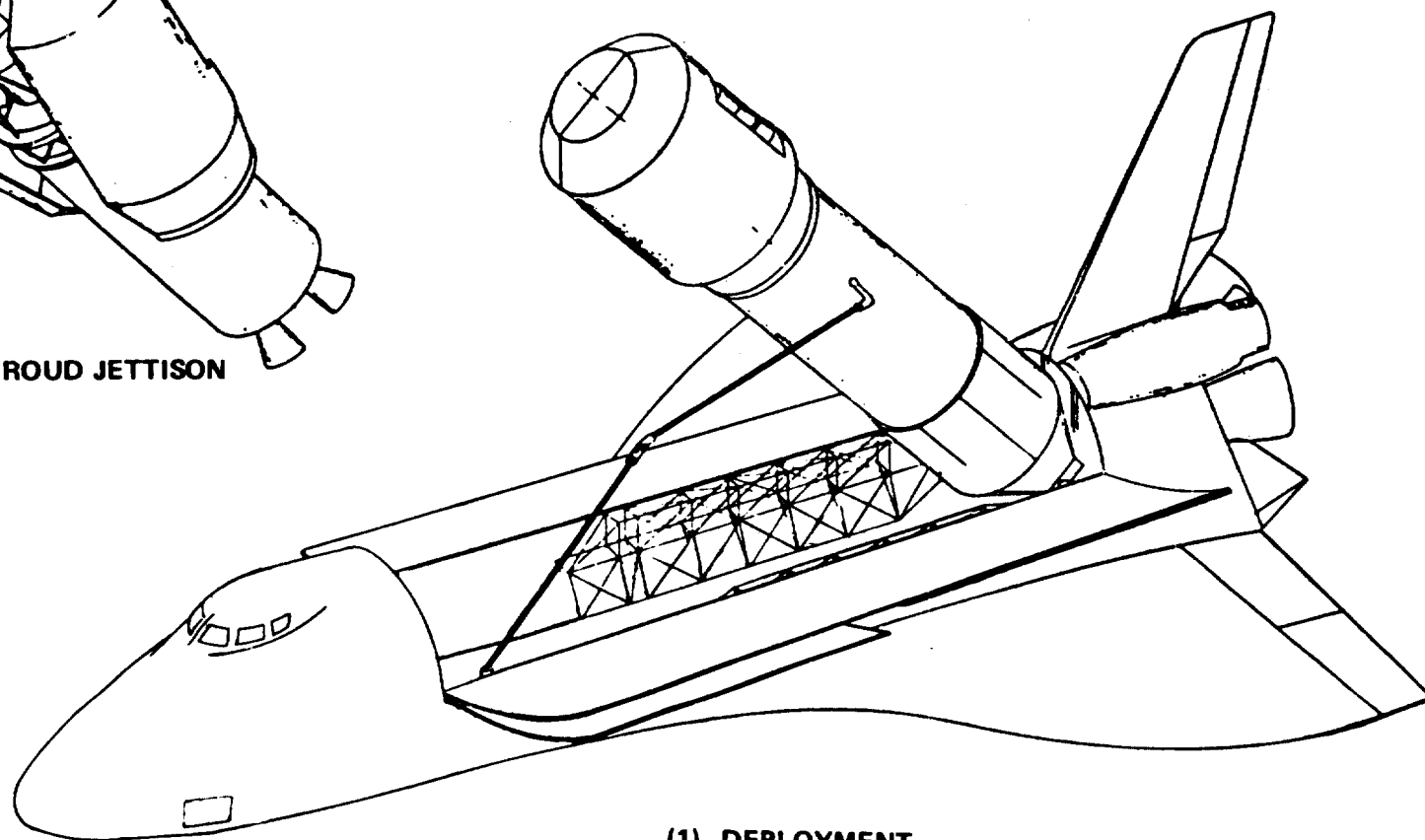
The primary effects of fluorine on spacecraft propulsion system design are to require tank insulation, ground cooling and relief line provisions, and fluorine compatible materials. Propulsion system design criteria which may be considered as recommended criteria for fluorine and good practice for N_2O_4 include:

1. System design should preclude significant pressure in the tankage during transportation from the loading site to the pad and during transportation in the Shuttle. The fluorine tank should be pressurized only after the SUS is deployed from the Shuttle Orbiter.
2. Fluorine (and probably N_2O_4) should be isolated in its tank by closed isolation valve mounted as close to the tank as practical. This state would be maintained until after Tug deployment from the Shuttle Orbiter.

3. Plumbing systems upstream and downstream from the isolation valves to the next valve should be passivated to provide a fail-safe redundant propellant containment.
4. Double wall tankage should be considered for LF_2 .
5. All associated equipment and procedures of the LF_2 system should be fail-fail-safe, or at least fail-safe.
6. Fail-safe operations are needed during propellant loading.
7. A leakage detector sensor is desirable between the walls if a double wall tank is used.
8. Caution and warning instrumentation should be provided and monitored during propellant loading, storage, transport to the pad, installation in the orbiter, in flight and during SUS deployment in orbit. Temperature, pressure and leakage information is required. Pressure transducers should have double redundant propellant containment.
9. In the spacecraft both types of oxidizer tanks would be relatively well protected from inadvertent mechanical damage. The LF_2 tank would have external insulation to the extent of approximately two to three inches of closed cell PBI foam. In addition, the LF_2 tank could incorporate a double wall. N_2O_4 tanks would be covered with multi-layer insulation.
10. Command signals to the spacecraft propulsion should be inhibited until the deployment in orbit away from the Shuttle.
11. It is desirable to have a vapor tight shroud (shroud concepts are shown in Figure 9-3).
12. It is desirable for cargo bay components to be metal, dense ceramics, and fully fluorinated elastomers.
13. Crew air intake (if any) should be effectively separated from propellant vent ports.
14. Combustible vapors and projectiles from other systems in cargo bay should be prevented.



(2) SHROUD JETTISON



(1) DEPLOYMENT

FROM JPL STUDY

Figure 9-3.

10. SAFETY GUIDELINES FOR LF_2 AS COMPARED TO N_2O_4

Safety guidelines for LF_2 as compared to those for N_2O_4 in the Space Shuttle context were found to be similar, and the fluorine guidelines almost without exception include those for N_2O_4 .

Significant differences relate to the somewhat different physical and chemical properties of these oxidizers. These differences come mainly from the cryogenic nature of liquid fluorine, the need for passivation of materials in contact with it, its hypergolicity with materials not ignited as rapidly by N_2O_4 , and its somewhat lower exposure limits under emergency and normal working conditions.

General fluorine safety guidelines are enumerated below, and cover all the activities of concern: system design, ground operations, and flight operations including abort for either propellant (the usual guidelines for propellant handling also apply):

1. Fail-safe tank cooling capability must be provided from loading through launch.
2. Adequate tank cooling must be provided during normal Shuttle flight and under emergency or Shuttle abort conditions. This may require an LN_2 cooling system in the orbiter.
3. Passivation of system hardware must be obtained including any redundant containers. Passivation should be protected from mechanical damage and from impurities in the fluorine, such as water which could yield hydrofluoric acid or other corrosive species.
4. Hardware for use with liquid fluorine must be of fluorine specific design and fabricated to high standards with emphasis on designs which will not lose passivation.
5. Materials surrounding a fluorine tank should, to the degree possible, be metallic materials, dense ceramics or fully fluorinated (e.g. Teflon), to minimize reaction with fluorine in case of a leak.

6. Personnel activities conducted near fluorine should be kept to a minimum, and loading operations should be conducted remotely. Although the exposure of personnel during normal operations tends to be low because of the infrequent nature of fluorine spacecraft launches, precautions must be observed to prevent threshold limit values (daily working limits) from being exceeded. Means to prevent exceeding Emergency Exposure Limits require protective suiting to be worn whenever leakages are even remotely possible, and isolation of unprotected personnel by suitable distances from possible spill.
7. Adequate personnel training and periodic practice of emergency procedures with fluorine are needed.

Figure 9-1 showed schematically a system which incorporates the desired features including propellant isolation. Figure 9-2 illustrated features of the double wall tank concept that could be used consistent with this system schematic.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

As a result of this study, a number of conclusions can be drawn about design criteria and requirements, and ground and flight procedures necessary to maximize the chance of safe and successful transport of a spacecraft fluorine propulsion system in the Space Shuttle. These conclusions are:

- The chance of an incident (hazard) occurring is reduced by isolating the LF_2 in the tank and not allowing any fluorine in valves or piping during handling of the loaded system on the ground or during the Shuttle phase of the flight.
- Current techniques for handling fluorine in commercial applications and at rocket test sites appear applicable, with refinements, to loading fluorine in payloads for Shuttle.
- Propellant should be loaded into the spacecraft at a remote location. The propulsion system should be monitored and allowed to stabilize prior to transporting and installing the spacecraft into the Shuttle.
- Use of an oxidizer dump system for LF_2 during flight appears technically feasible, but the entire dump question requires further investigation.
- Risk to personnel is best reduced by excluding people from proximity to toxic materials during the processing, and by providing effective protective clothing and by instituting careful "back-out" procedures.
- In order to achieve the required level of safety with fluorine some additional Shuttle pre-launch operations time, in the order of a few hours, may be needed.

- The safety effort required to control hazards to protect equipment, facilities and personnel is significant and may be justifiably higher than for previous, unmanned spacecraft. It is expected, however, that safety related costs will be a fraction of propulsion costs.
- The safety program for fluorine should be started and implemented during the hardware development phase, should be oriented towards specific goals and should incorporate the System Safety Engineering approach throughout the program.
- A safety assurance function in cooperation with the quality control function must be provided to assure that all safety requirements are met when the payload is installed into the Orbiter.
- The effects of residual hazards during flight in the Space Shuttle Orbiter Cargo bay from properly isolated propellants in a propulsion system which has been loaded and stored prior to transportation on the Shuttle appear low and the number of residual hazards appear few provided that hazards to the propulsion system from other systems are minimized.
- Transportation of the system should be in the unpressurized (or nearly unpressurized) state to minimize the effects of any leaks (ICC regulations limit transportation on highways to 300 psi).
- The concept of a "propulsion garage" at the launch complex for safe storage of the loaded propulsion system during the verification period after loading and prior to launch is suggested.
- The use of double (redundant) wall pressure vessels for oxidizer containment is suggested
- Propellant vapor detection in the void between shells is suggested.
- Use of inert gas in fluorine dump lines to protect the passivation and to provide verification of dump line integrity (if dump provisions are required) is suggested.

11.2 Recommendations

Additional system safety engineering and propulsion system design engineering efforts are recommended as indicated below. Close coordination with the Shuttle Orbiter and Tug designers will be required as it was during the execution of this study.

1. A more complete definition of the implications of and need for a propellant dump system for fluorine considering the actual technology available for such a system and more complete definition of the impacts to the Shuttle Orbiter design. This should include a) dump valve and line design, b) reliability considerations and c) a safety comparison (dump versus no dump).
2. Propellant tank design and demonstration activity to demonstrate the feasibility of lightweight, long term fluorine containment in a redundant wall tank.
3. Advanced development of long-life, leak-tight propellant isolation valves in the 1 to 2 inch line size which will allow propellant to be dumped within the allowable time constraint (if dump is required).
4. Continued definition of the propulsion system, including shroud and line routings especially for the coolant (and dump lines, if required).
5. Technology work on the propulsion system which will allow fully realistic design layouts to be made.
6. Advanced development of LF_2 and N_2O_4 vapor detection equipment.
7. A study of the requirements for equipment to accomplish safe landings and aborts to landing sites of opportunity.